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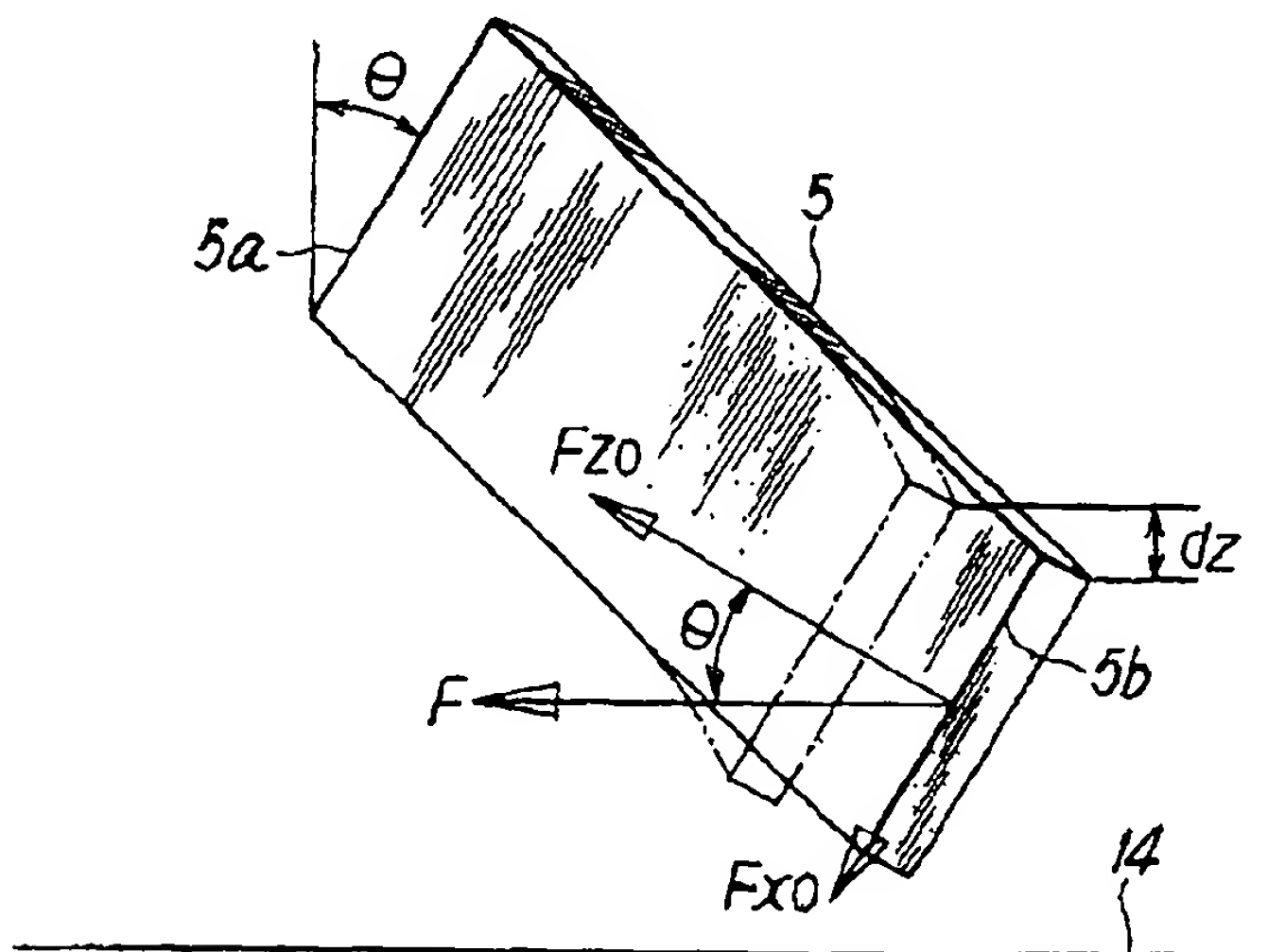
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(54) Electrostatic actuator driven slider displacement direction conversion mechanism

(57) There is provided a slider displacement direction conversion mechanism which can convert the displacement direction of a slider from a direction perpendicular to a substrate surface. The slider is displaced by electrostatic force parallel to the substrate surface generated by an electrostatic actuator and at least one elas-

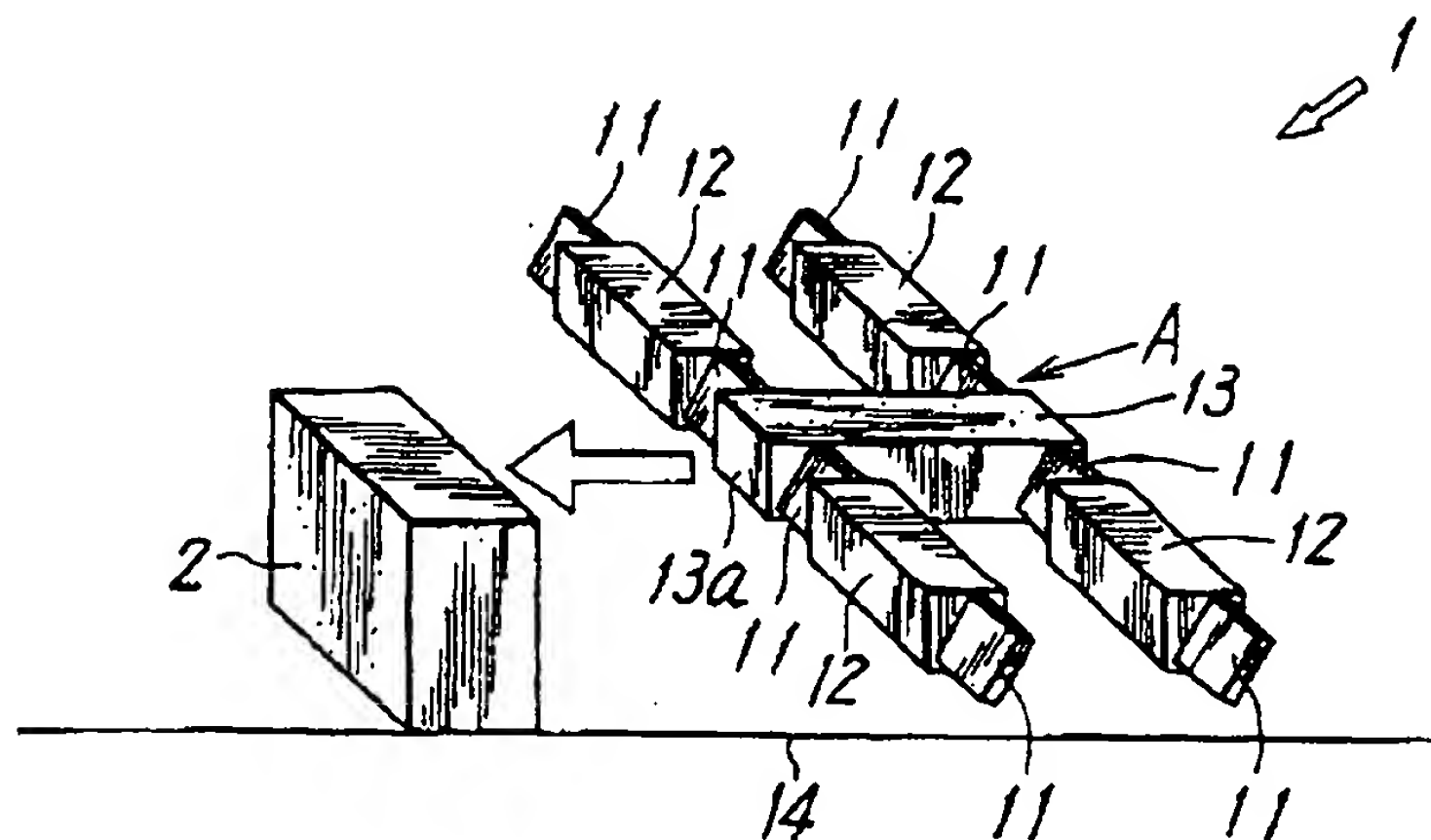
tic beam fixed to a substrate which support the slider. The elastic beams are provided with at least one displaceable member supporting the slider, and the displaceable member is easily displaced in the direction different from the displacement direction when the slider is subjected to force in the displacement direction.

FIG. 1a



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FIG. 1b



## Description

[0001] The present invention relates to a mechanism for converting the displacement direction of a slider which is driven by an electrostatic actuator in a structure on a surface of a substrate such as a silicon formed by using a technology such as photolithography.

[0002] Figure 6 shows a known system in which a slider (a shuttle) 52 is displaced by using an interdigital electrostatic actuator 50 in order to continuously control the displacement of the slider 52 in a structure on the surface of a substrate formed of silicon or the like by using a technology such as photolithography.

[0003] The electrostatic actuator 50 comprises a fixed side interdigital electrode 54 and a movable side interdigital electrode 55, the movable side interdigital electrode 55 is mounted on a fitting portion 53 at an end of the slider 52, and the slider 52 is displaced in a direction parallel to a substrate surface 51 by generating the electrostatic force between the interdigital electrodes 54, 55.

[0004] In addition, in order to displace the slider in the perpendicular direction, a method of generating an electrical field E perpendicular to the substrate surface 51 has been employed as shown in Fig. 7.

[0005] With the known interdigital electrostatic actuator 50 shown in Fig. 6, although the displacement can be continuously controlled, motion is limited to the horizontal direction with respect to the substrate surface 51 and no means is provided which allows motion in the perpendicular direction with respect to the substrate surface 51.

[0006] Further, in the method of generating an electric field perpendicular to the substrate surface 51 as shown in Fig. 7, the displacement is small, and the continuous control is less easily implemented, and the slider cannot be displaced in a direction which separates it from the substrate surface.

[0007] An object of the present invention is to provide a slider displacement direction conversion mechanism in an electrostatic actuator in which the displacement direction of the slider can be converted to the perpendicular direction with respect to the substrate surface.

[0008] Another object of the present invention is to provide a slider displacement direction conversion mechanism in an electrostatic actuator in which displacement of the slider in the direction parallel to the substrate surface is prevented and displacement in the upwardly perpendicular direction with respect to the substrate surface is increased.

[0009] A slider displacement direction conversion mechanism in an electrostatic actuator in accordance with the invention comprises at least one electrostatic actuator which generates electrostatic force parallel to the substrate surface, at least one slider which is displaced under the force from the electrostatic actuator, and at least one elastic beam fixed to the substrate supporting the slider, the elastic beam has displaceable members which entirely or locally support the slider, and

the displaceable members are characterised in that they are easily displaced in a direction different from the displacement direction when the slider is subjected to the force in the displacement direction.

[0010] The slider displacement direction conversion mechanism preferably has a leaf spring structure in which one end of the elastic beam is fixed to the substrate in an inclined manner to the substrate surface, and the other end thereof is fixed to the slider, and the entire elastic beam forms the displaceable member. The elastic beam may have a strip like projecting piece which is inclined to the substrate surface on both ends thereof, the strip like projecting pieces on both ends forming the displaceable member, and the elastic beam being fixed to the substrate via the other strip like projecting piece.

[0011] Preferably, each strip like projecting piece is suitably formed by providing a notched portion in a part of the elastic beam, the displaceable member of the elastic beam is disposed so as to be easily displaced on a predetermined direction, and a plurality of elastic beams are disposed so that each displaceable member is easily displaced in the same direction.

[0012] Preferably, the plurality of elastic beams are disposed so as to support forward and rear portions of the slider, the forward and rear elastic beams are suitably disposed so that each displaceable member thereof is easily displaced in different directions.

[0013] In one embodiment first and second sliders are disposed parallel to each other, the first slider is supported by the substrate via the displaceable member of the elastic beam fixed to the substrate, the second slider is supported by the first slider via the displaceable member of the elastic beam, and driving forces in the reverse direction to each other are given from first and second electrostatic actuators to the first and second sliders so that the displacement in the direction parallel to the substrate surface of the second slider is cancelled, and the displacement in the upwardly perpendicular direction with respect to the substrate surface is increased.

[0014] In a preferred form, two of the first sliders are supported in parallel by the substrate via the displaceable member of the outer elastic beam fixed to the substrate, one of the second sliders is disposed between the two first sliders, the second slider is respectively supported by the two first sliders via the displaceable member of the inner elastic beam, the displaceable member of the outer elastic beam is a plate-like displaceable member inclined at a counterclockwise angle with respect to the substrate while the displaceable member of the inner elastic beam is a plate-like displaceable member inclined at a clockwise angle from the substrate.

[0015] When the electrostatic actuator generates the electrostatic force, the elastic beam supporting the slider is subjected to the force to generate the displacement parallel to the substrate.

[0016] Since the displaceable member of the elastic beam supporting the slider is easily displaced in the di-

rection different from the force applying direction, the displaceable member of the elastic beam is displaced by a specific angle with respect to the direction of the force.

[0017] As a result, the slider supported by the displaceable member of the elastic beam is displaced so as to have a component of motion in the perpendicular direction with respect to the substrate.

[0018] The invention will now be described by way of example with reference to the accompanying drawings in which:

Fig. 1a is a partly perspective view showing an enlarged portion A of Fig. 1b in order to indicate the principle of the present invention, and Fig. 1b is a perspective view showing an embodiment of a slider displacement direction conversion mechanism of the present invention,

Fig. 2 is a perspective view showing a similar embodiment to that of Fig. 1b.

Fig. 3 is a perspective view showing another embodiment of the slider displacement direction conversion mechanism in the electrostatic actuator of the present invention.

Fig. 4 is a perspective view similarly showing another embodiment.

Fig. 5 is a perspective view similarly showing another embodiment.

Fig. 6 is a plan view showing a conventional interdigital electrostatic actuator.

Fig. 7 is a cross-sectional view through the line B-B in Fig. 6.

[0019] One embodiment of a slider displacement direction conversion mechanism 1 comprises two pairs of elastic beams 12 having two displaceable members 11 on both end faces thereof with an appropriate space therebetween as shown in Fig. 1b or Fig. 2, and a slider 13 is disposed so as to be located on a tip of one displaceable member 11 of each elastic beam 12. The number of the elastic beams may be arbitrarily determined but at least three.

[0020] The displaceable members 11 comprise a strip-like projecting piece disposed on both end faces of the elastic beam 12 in the same direction inclined at a counterclockwise angle with respect to a substrate 14 in the figure. The strip-like projecting piece forming the displaceable members 11 is a member which is easily displaced in a direction different from the displacement direction when the slider is subjected to the force in the displacement direction, and the strip-like projecting piece is formed by providing a notched portion in a part

of the elastic beam 12.

[0021] One electrostatic actuator 2 which generates the electrostatic force parallel to a substrate surface is disposed on the substrate 14, the electrostatic actuator 2 comprises a fixed side interdigital electrode and a movable side interdigital electrode similar to those in Fig. 6, the movable side interdigital electrode is mounted on a fitting portion 13a at an end of the slider 13, and the slider 13 is displaced in the horizontal direction with respect to the surface of the substrate 14 by generating the electrostatic force between the fixed side interdigital electrode and the movable side interdigital electrode.

[0022] The electrostatic actuator 2, the slider 13 and the elastic beam 12 are manufactured by using the technology such as photolithography.

[0023] The displaceable members 11 of the elastic beam 12 are inclined to the surface of the substrate 14 as described above, one of the displaceable members 11 is fixed to the slider 13, and the other of the displaceable members 11 is fixed to a fixed portion (not shown in the figure) which is integrally formed on the substrate 14 in the horizontal direction.

[0024] The displaceable member 11 is shown as a leaf spring 5 in Fig. 1a, and a fixed end 5a thereof is fixed to the substrate 14 in an inclined manner by the fitting angle  $q$  with respect to the normal direction of the substrate 14, and a tip 5b thereof is fixed to the slider 13 or the elastic beam.

[0025] Since the slider 13 is subjected to the electrostatic force  $F$  parallel to the surface of the substrate 14 by the electrostatic actuator 2, the electrostatic force  $F$  is applied to the tip 5b as shown in Fig. 1a.

[0026] The electrostatic force  $F$  generates the force component  $F_{x0}$  in the width direction of the leaf spring 5 and the force component  $F_{z0}$  in the thickness direction orthogonal to the width direction of the leaf spring 5. However, the leaf spring 5 has a high rigidity in the force direction of  $F_{x0}$ , and has a relatively low rigidity in the force direction of  $F_{z0}$ , and the leaf spring is little displaced in the force direction of  $F_{x0}$ , but mainly displaced in the force direction of  $F_{z0}$ .

[0027] As a result, the displacement  $dz$  in the perpendicular direction is generated at the tip 5b of the leaf spring 5 with respect to the surface of the substrate 14.

[0028] As described above, the displaceable member 11 comprises the strip-like projecting piece disposed on both end faces of the elastic beam 12 in the same direction with a counterclockwise angle of inclination with respect to the surface of the substrate 14, the slider 13 is fixed to the tip of one displaceable member 11, and the other displaceable member 11 is fixed to the substrate 14, and as shown in Fig. 2, when the slider 13 is subjected to the electrostatic force  $F$  in the left direction parallel to the surface of the substrate 14, the displaceable members 11 disposed on a plurality of elastic beams 12 are displaced in the same direction, and as a result, the slider 13 is displaced upward to the left while constantly maintaining the same angle of inclination with

respect to the substrate 14, and the distance from the substrate 14 is increased, accordingly.

[0029] Fig. 3 shows another embodiment of the slider displacement direction conversion mechanism in the electrostatic actuator of the present invention.

[0030] In the embodiment in Fig. 3, two pairs of elastic beams 22 having two displaceable members 21 on both end faces are disposed with a suitable space therebetween, and a slider 23 is disposed so as to be located on a tip of one displaceable member 21 of each elastic beam 22.

[0031] The displaceable members 21 comprise strip-like projecting piece disposed on both end faces of the elastic beam 22 at different angles from each other with respect to the substrate 24.

[0032] This means that, in Fig. 3, the displaceable member 21 on the right elastic beam is inclined at a counterclockwise angle with respect to the substrate with respect to the substrate 24, while the displaceable member 21 on the left elastic beam is inclined at a clockwise angle with respect to the substrate 24.

[0033] An electrostatic actuator 2, the slider 23 and the elastic beam 21 are disposed on the substrate 24 by using the technology such as photolithography, the slider 23 has a fitting portion 23a with a movable side interdigital electrode mounted on an end thereof, and the electrostatic actuator 2 generates the electrostatic force between the fixed side interdigital electrode and the movable side interdigital electrode, and displaces the slider 23 in the horizontal direction with respect to the surface of the substrate 24.

[0034] When the slider 23 is subjected to the electrostatic force F in the left direction parallel to the surface of the substrate 24, the displaceable members 21 disposed on the plurality of elastic beams 22 are displaced in different directions, and as a result, the slider 23 is inclined at a counterclockwise angle with respect to the substrate 24, and the distance from the substrate 24 is changed thereby.

[0035] Fig. 4 shows still another embodiment of the slider displacement direction conversion mechanism in the electrostatic actuator of the present invention.

[0036] In the embodiment shown in Fig. 4, the slider displacement direction conversion mechanism 1 in the electrostatic actuator comprises two outer sliders 33 disposed on a substrate 34 parallel to each other, one inner slider 36 disposed between the two outer sliders 33, total four sets of outer elastic beams 32 with each set thereof comprising one pair of the outer elastic beams supporting the two outer sliders 33, total four sets of inner elastic beams 35 with each set thereof comprising one pair of inner elastic beams supported by the outer sliders 33, total four fixed portions 39 integrally disposed on the substrate 34 in the perpendicular direction in the vicinity of side walls of the outer sliders 33, and two electrostatic actuators 2 disposed on the substrate 34 facing both sides in the axial direction of the outer sliders 33 and the inner slider 36.

[0037] The electrostatic actuators 2, the outer sliders 33, the inner slider 36, the outer elastic beams 32, the inner elastic beams 35, and the fixed portions 39 are disposed on the substrate 34 by using the technology such as photolithography, the outer sliders 33 and the inner slider 36 have fitting portions 33a, 36a with a movable interdigital electrode mounted on ends thereof, and the electrostatic actuators 2 generate the electrostatic force between the fixed side interdigital electrode and the movable side interdigital electrode, and displace the outer sliders 33 and the inner slider 36 in the horizontal direction with respect to the surface of the substrate 34.

[0038] The outer sliders 33, the inner slider 36, the outer elastic beams 32, the inner elastic beams 35 and the fixed portions 37 are symmetrical to the axis in the axial direction.

[0039] The pair of outer elastic beams 32 are disposed parallel to each other, and the displaceable members 31 which are formed of the strip-like projecting pieces similar to those shown in Fig. 2 and inclined at a counterclockwise angle with respect to the substrate 34 are disposed on both end faces of the outer elastic beams 32.

[0040] Side walls of the outer sliders 33 are fixed to one elastic beam 32 of the pair of outer elastic beams 32 via the displaceable members 31, the other elastic beam 32 of the pair of outer elastic beams 32 is fixed to the fixed portions 39 via the displaceable members 31, and the displaceable members 31 on the end face on the opposite side to the pair of outer elastic beams 32 are respectively fixed to connection plates 38.

[0041] Thus, the outer sliders 33 are supported by the substrate 34 via one elastic beam 32 of the pair of outer elastic beams 32, the connection plates 38, the other elastic beam 32 of the pair of outer elastic beams 32, and the fixed portions 39.

[0042] The pair of inner elastic beams 35 are disposed parallel to each other, and the displaceable members 37 which are symmetrical to the displaceable members 31 disposed on both end faces of the outer elastic beams 32, formed of the strip-like projecting pieces and inclined at a clockwise angle with respect to the substrate 34 are respectively formed on both side surfaces of the inner elastic beams 35.

[0043] One elastic beam 35 of the pair of inner elastic beams 35 is fixed to an inner side wall of the outer slider 33 via the displaceable member 37 thereof, the other elastic beam 35 of the pair of inner elastic beams 35 is fixed to the inner slider 36 via the displaceable member 37 thereof, and the displaceable members 37 on the end face on the opposite side of the pair of inner elastic beams 35 are fixed to the connection plates 38, respectively.

[0044] Therefore, the inner slider 36 is supported by the outer sliders 33 via the other elastic beam 35 of the pair of inner elastic beams 35, the connection plates 38, and one elastic beam 35 of the pair of inner elastic beams 35.



[0045] In the embodiment shown in Fig. 4, the displaceable members 31 which are formed of the strip-like projecting pieces and inclined at a counterclockwise angle with respect to the substrate 34 are formed on the outer elastic beams 32 which support the outer sliders 33 and are supported by the substrate 34, the displaceable members 37 which are formed of the strip-like projecting pieces and inclined at a clockwise angle with respect to the substrate 34 are formed on the inner elastic beams 35 which support the inner slider 36 and are supported by the outer sliders 33. Thus, when the electrostatic force F1 in the left direction is applied to the outer sliders 33 by one electrostatic actuator 2, the outer sliders 33 and the inner slider 36 supported thereby are displaced upward to the left, and when the electrostatic force F2 in the right direction is applied to the inner slider 36 by the other electrostatic actuator 2, the inner slider 36 is displaced upward to the right.

[0046] Thus, when the two electrostatic actuator 2 are simultaneously operated, the displacement in the left horizontal direction of the outer sliders 33 is canceled by the displacement in the right horizontal direction of the inner slider 36, and as a result, the inner slider 36 is displaced by the doubled displacement upwardly in the perpendicular direction.

[0047] Fig. 5 shows further another embodiment of the slider displacement direction conversion mechanism in the electrostatic actuator of the present invention.

[0048] The embodiment shown in Fig. 5 has basically the same structure as that of the embodiment shown in Fig. 2, except that an entire elastic beam 41 forms a displaceable member.

[0049] The elastic beams 41 according to the embodiment shown in Fig. 5 have a leaf spring structure in which one end thereof is fixed to a substrate 44 in an inclined manner with respect to the substrate surface thereof, and the other end thereof is fixed to the slider 43, and the entire elastic beams 41 form the displaceable members.

[0050] The slider 43 has a fitting portion 43a with a movable side interdigital electrode mounted on an end thereof, and the slider 43 is displaced in the horizontal direction with respect to the surface of the substrate 44 by generating the electrostatic force between the fixed side interdigital electrode and the movable side interdigital electrode of the electrostatic actuator 2.

[0051] The present invention is described above with reference to the embodiments, however, the present invention is not limited to these embodiments, and the embodiments can be arbitrarily modified within the scope of the present invention.

## Claims

1. A slider displacement direction conversion mechanism for at least one slider which is displaced under

electrostatic force parallel to a substrate surface generated by an electrostatic actuator, the slider being supported by at least one elastic beam fixed to the substrate supporting said slider, wherein the elastic beam has at least one displaceable member which supports the slider, and wherein the displaceable member is easily displaced in a direction different from a displacement direction when the slider is subjected to a force in the displacement direction.

2. A slider displacement direction conversion mechanism according to Claim 1, wherein the elastic beam has a leaf spring structure and one end of the elastic beam is fixed to the substrate at an incline to the substrate surface, and the other end is fixed to the slider.
3. A slider displacement direction conversion mechanism according to Claim 2, wherein the elastic beam has a strip-like projecting piece which is inclined to the substrate surface at both ends thereof, and wherein the strip-like projecting pieces form the displaceable members, and the elastic beam is fixed to the slider by one strip-like projecting piece and to the substrate via said other strip-like projecting piece.
4. A slider displacement direction conversion mechanism according to Claim 3, wherein each strip-like projecting piece is formed by providing a notched portion in a part of said elastic beam.
5. A slider displacement direction conversion mechanism according to any preceding claim, wherein the or each displaceable member of the elastic beam is disposed so as to be easily displaced in a predetermined direction, and a plurality of elastic beams are disposed so that each displaceable member thereof is easily displaced in the same direction.
6. A slider displacement direction conversion mechanism according to any preceding claim, wherein there are first and second sliders disposed parallel to each other, the first slider is supported by the substrate via a first displaceable member of the elastic beam which is fixed to the substrate, and the second slider is supported by the first slider via a second displaceable member of the elastic beam, and wherein first and second electrostatic actuators provide driving forces in opposite directions to the first and second sliders so that displacement in the direction parallel to the substrate surface of the second slider is prevented and displacement in the upwardly perpendicular direction with respect to the substrate surface is increased.
7. A slider displacement direction conversion mechanism according to Claim 6, wherein two first sliders

are supported in parallel to each other by the substrate via a displaceable member of an outer elastic beam fixed to the substrate, wherein one of two second sliders is disposed between the two first sliders, and said second slider is supported by the two first sliders via a displaceable member of an inner elastic beam, wherein the displaceable member of the outer elastic beam is a plate-like displaceable member inclined at a counterclockwise angle with respect to the substrate, and wherein the displaceable member of the inner elastic beam is a plate-like displaceable member inclined at a clockwise angle with respect to the substrate.

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FIG. 1a

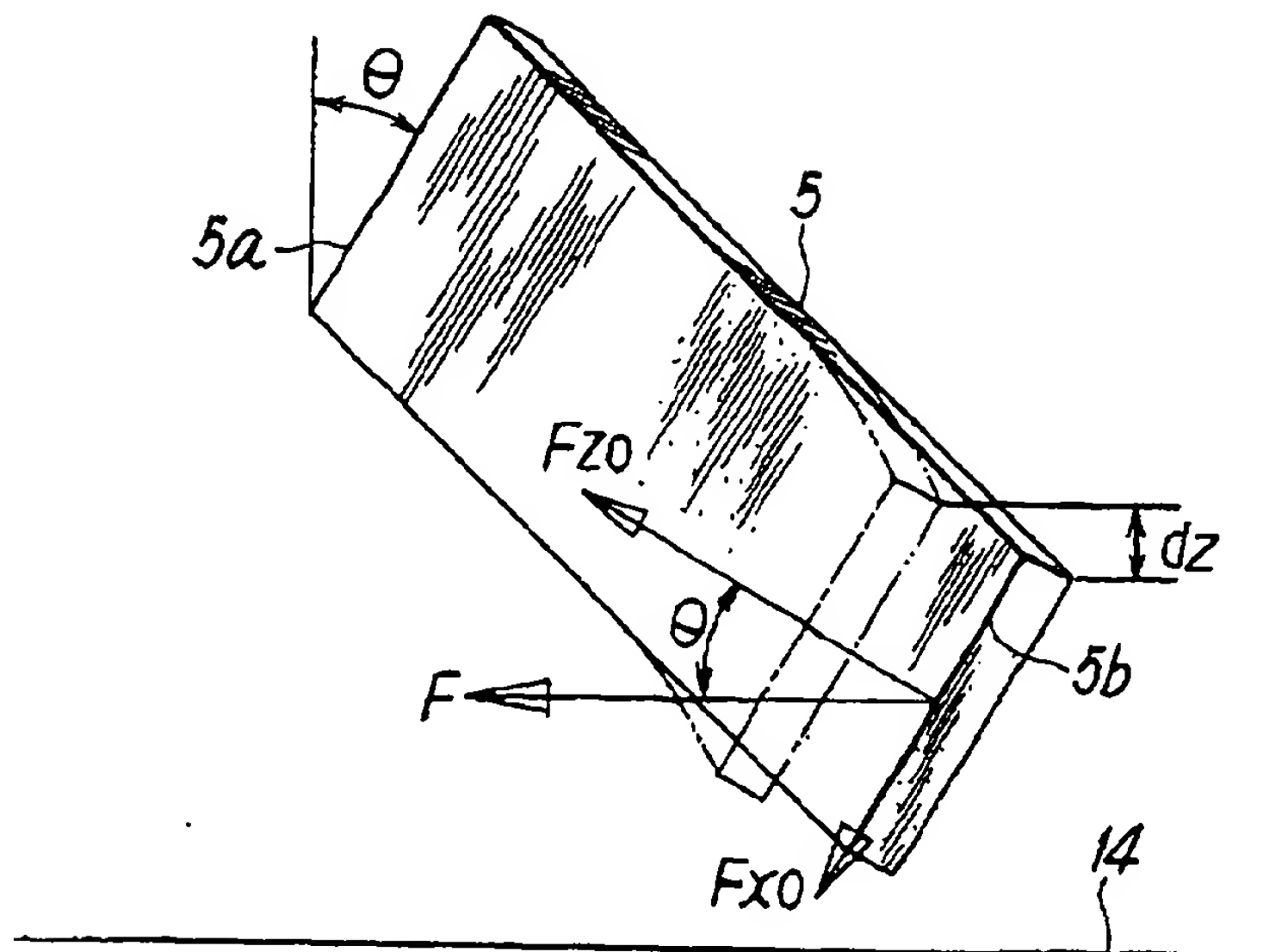


FIG. 1b

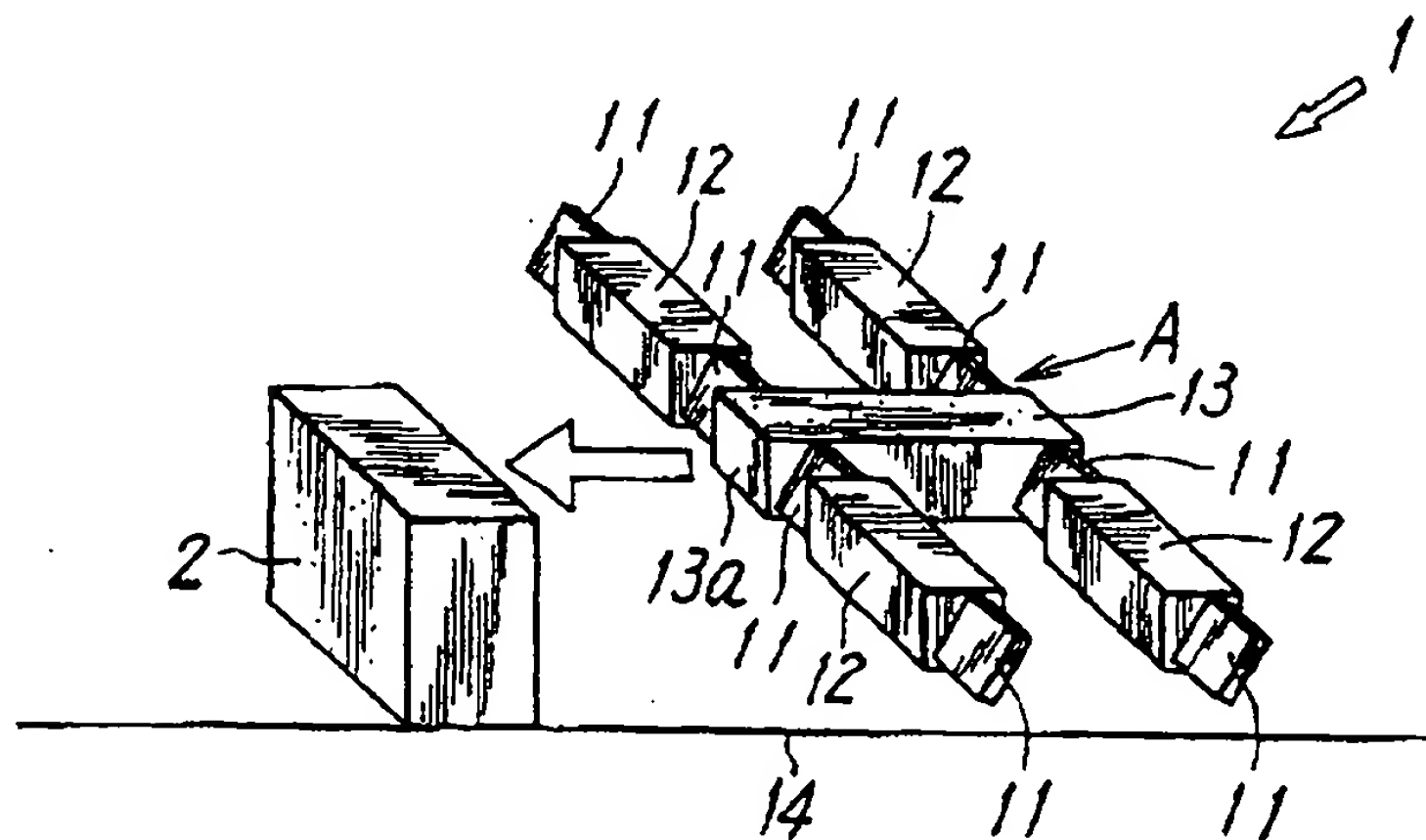




FIG. 2

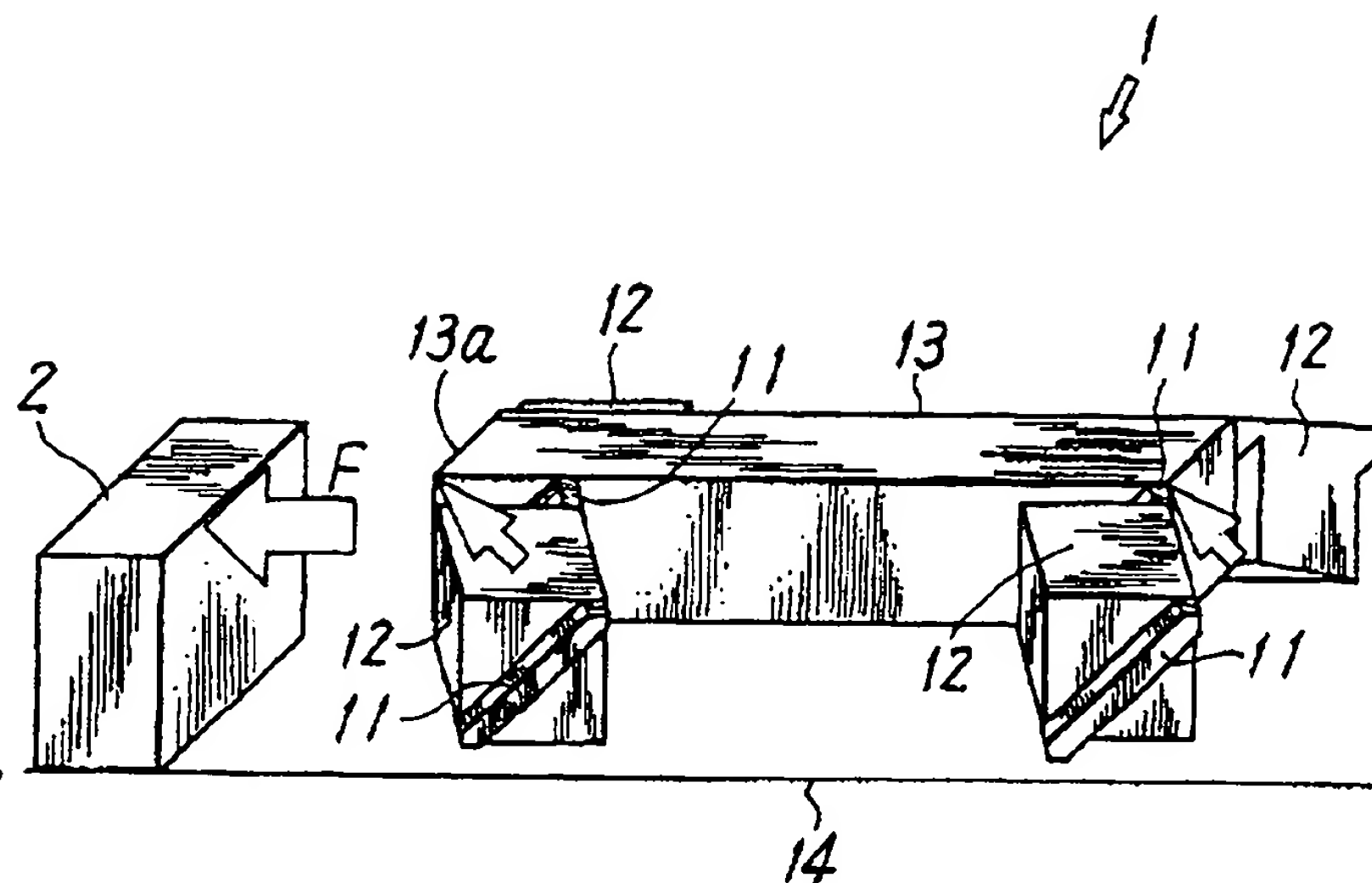


FIG. 3

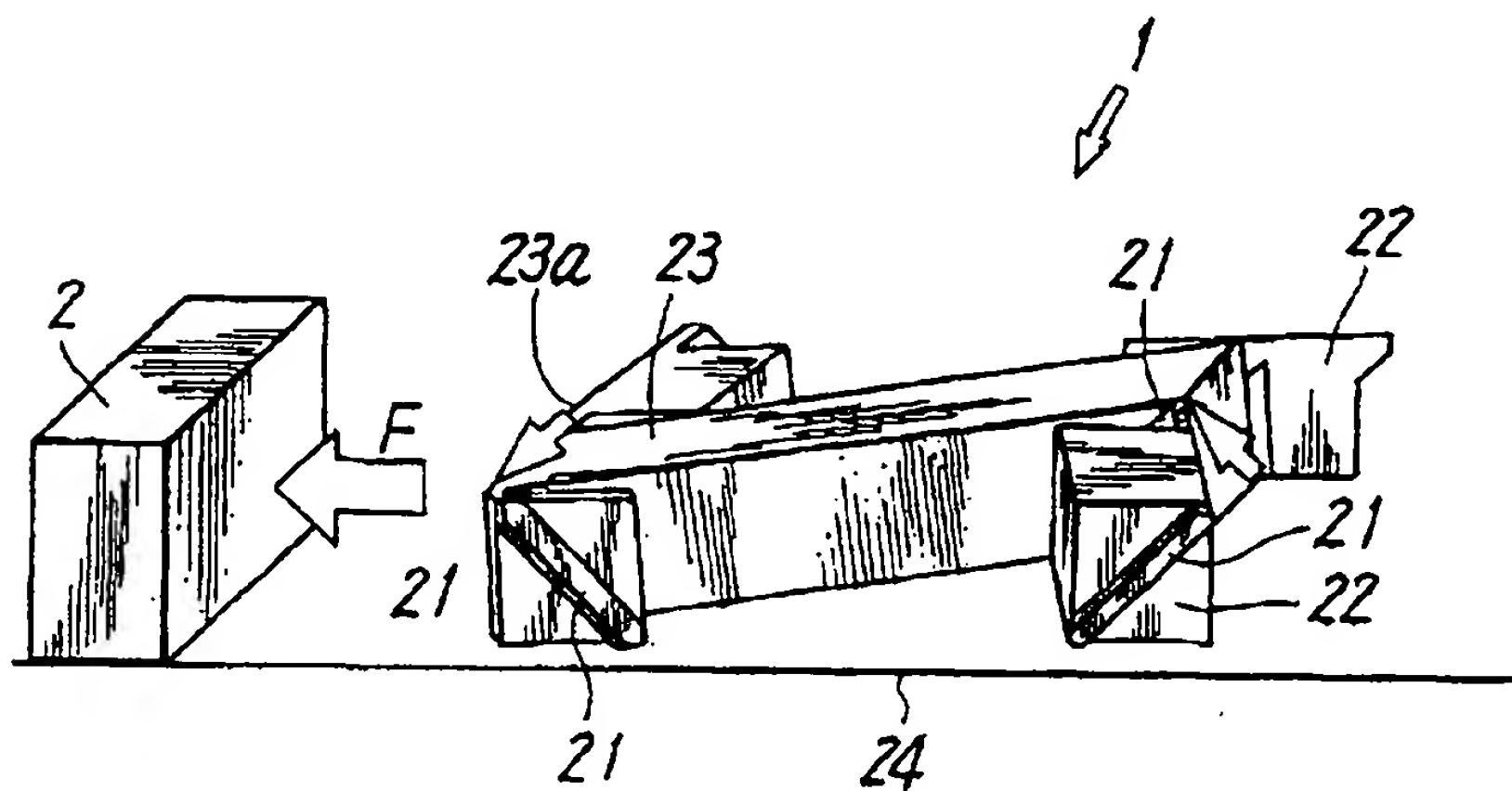


FIG. 4

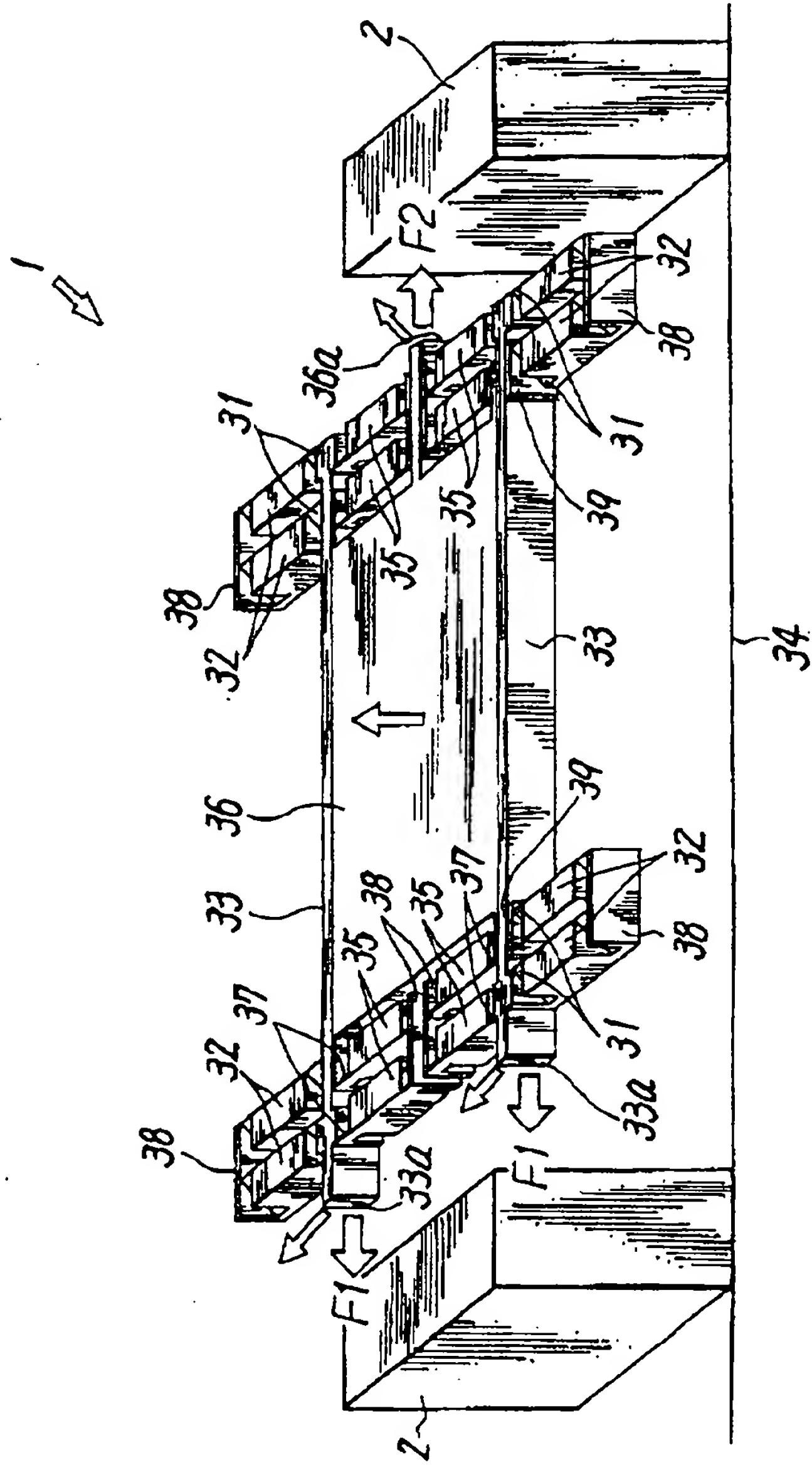


FIG. 5

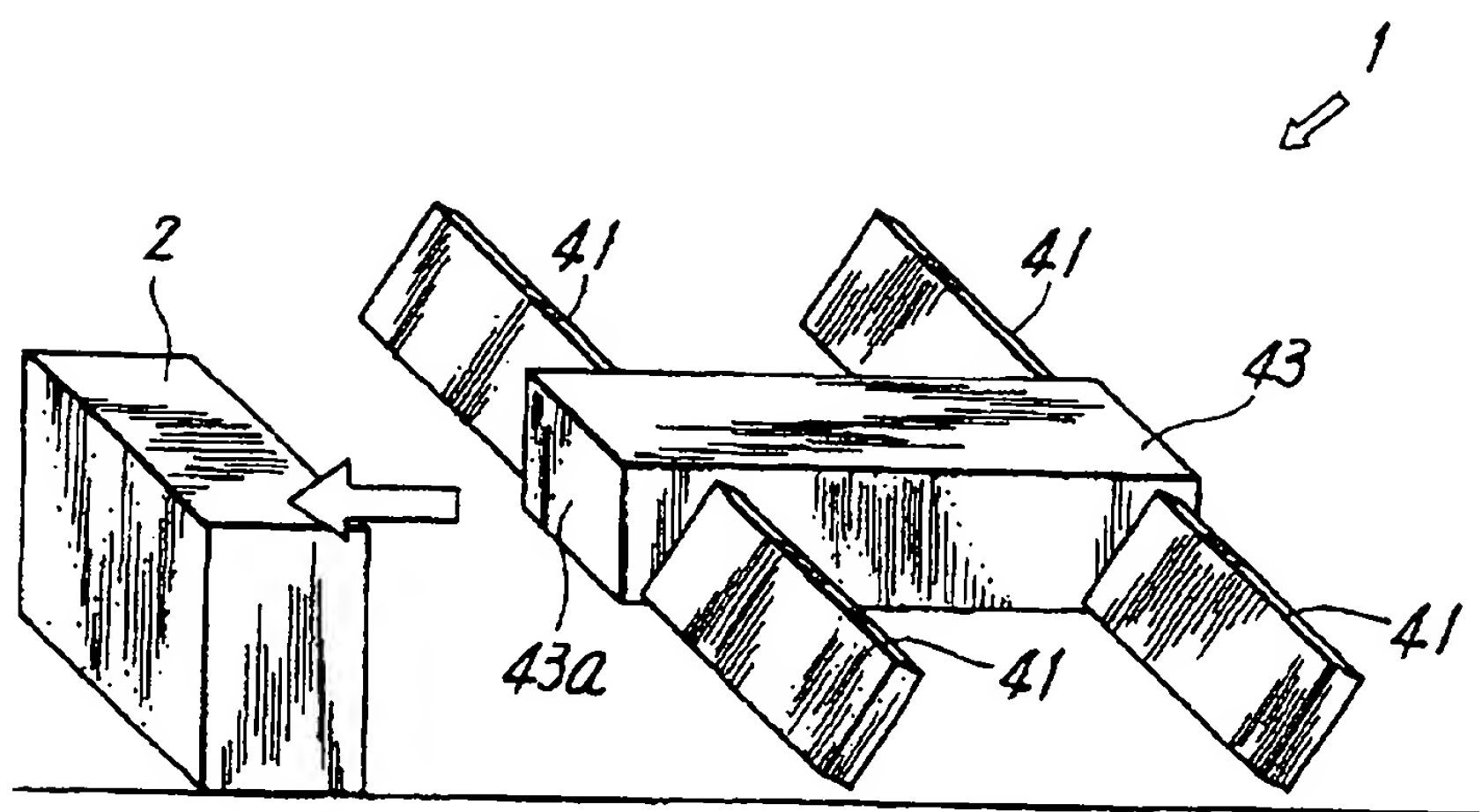


FIG. 6

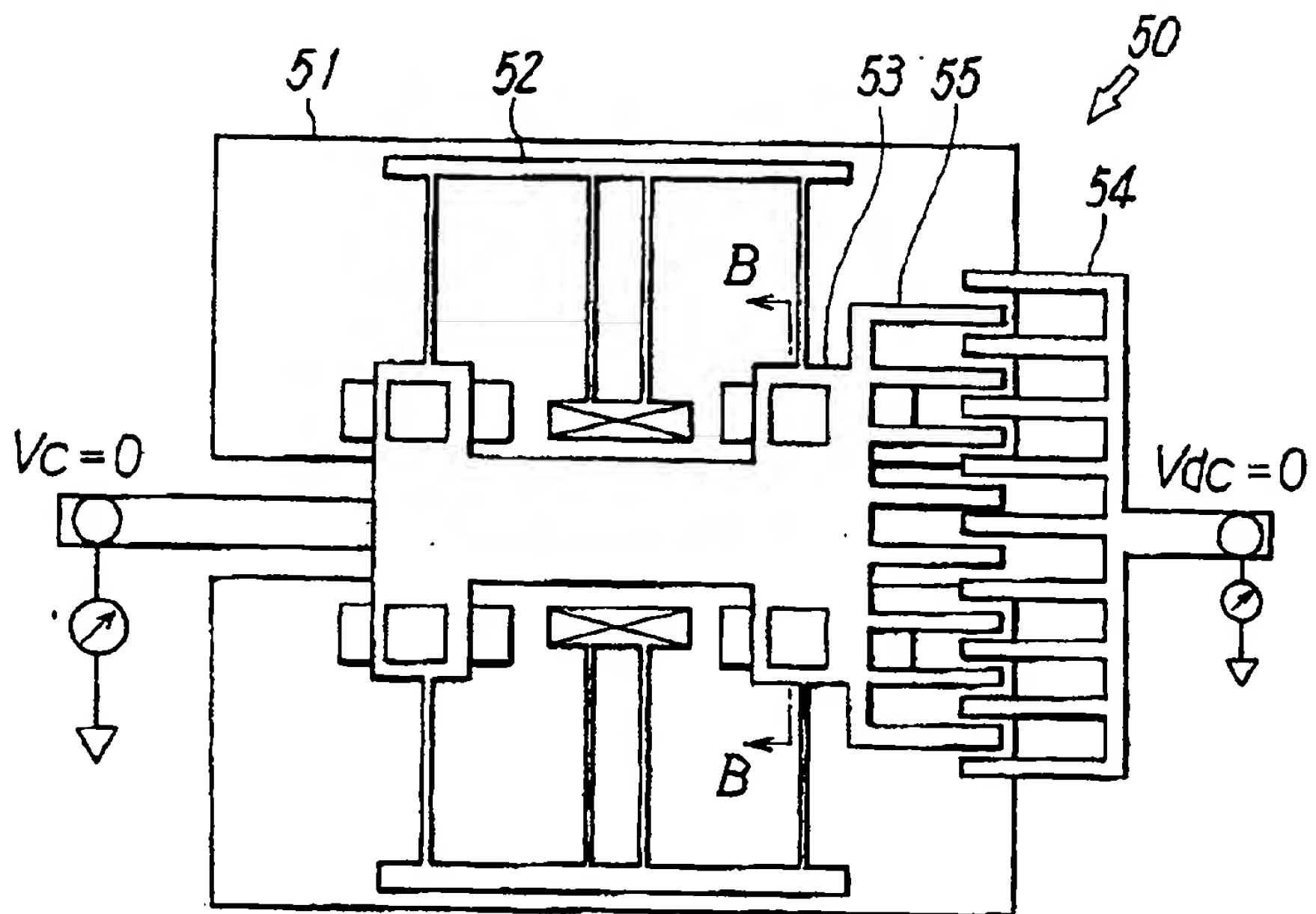


FIG. 7

